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Effects of storage in slurry ice on the microbial, chemical and sensory quality and on the shelf life of farmed turbot (*Psetta maxima*)

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Abstract

The application of slurry ice, a binary mixture of small spherical ice crystals surrounded by seawater at subzero temperature, is a potentially new preservation method for farmed turbot (*Psetta maxima*), a flat fish species of increasing commercial interest. Comparative biochemical, microbiological and sensory analyses were carried on turbot specimens stored in either slurry ice or flake ice for up to 40 days. The results obtained in the sensory analysis correlated well with the observed chemical and microbial changes. Storage of turbot in slurry ice resulted in a slowing-down of the nucleotide degradation pathway and lipid oxidation mechanisms. A good stabilisation of the high molecular weight protein fraction of turbot muscle was also achieved as a consequence of storage in slurry ice. A slower production of both trimethylamine and total volatile bases was also observed. Likewise, low levels of total aerobes, anaerobes, coliforms, and proteolytic bacteria were attained. The application of slurry ice to farmed turbot is advisable to achieve better quality maintenance during storage and distribution.

Keywords: Chilling; Slurry ice; Turbot; Aquaculture; Shelf life; Quality

1. Introduction

Marine species deteriorate rapidly after death due to the effect of a wide variety of biochemical and microbial degradation mechanisms. However, the loss of quality depends directly on the nature of fish species and on the handling and storage conditions (Olafsdóttir et al., 1997; Whittle, Hardy, & Hobbs, 1990). Once the fish are caught, on-board storage conditions exert a strong effect on the quality of manufactured fish products and, accordingly, on their commercial value (Ashie, Smith, & Simpson, 1996; Piggot & Tucker, 1987). With a view to preserving the greatest proportion of a fish catch in an acceptable manner, several on-board handling systems, including storage in flake ice (Nunes, Batista, & Morâo de Campos, 1992), refrigerated seawater (Kraus, 1992), or the addition of chemicals (Hwang & Regenstein, 1995; Ponce de León, Inoue, & Shinano, 1993), have been proposed.

Slurry ice, also known as fluid ice, slush ice, liquid ice or flow ice, offers a promising technique for preservation and consists of an ice–water suspension at a subzero temperature. Two main features of slurry ice are its faster chilling rate, deriving from its higher heat-exchange capacity, and the reduced physical damage caused to seafood products by its microscopic spherical particles, as compared with flake ice. The overall covering of the fish surface by the slurry ice mixture also protects the

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fish from the action of oxygen. The versatility of the slurry ice technique has also been highlighted. Besides being a pumpable mixture, slurry ice may be combined with other additives, such as ozone or melanosis inhibitors (Huidobro, López-Caballero, & Mendes, 2002). However, despite its theoretical advantages few empirical data concerning the practical advantages derived from the use of slurry ice for the storage of marine species are available.

Fish technologists and the fish trade in general are paying increasing attention to aquaculture products as a source of fish and other seafood products (FAO, 2003; Josupeit, Lem, & Lupin, 2001). Such is the case of turbot (*Psetta maxima* also known as *Scophtalmus maximus*), a highly valued flat fish species appreciated for its firm, white and flavorful flesh. Recently, increasing production of this species as an aquaculture product has raised its availability. However, previous research on farmed turbot has mainly focused on farming conditions (Sérot, Regost, Prost, Robin, & Arzel, 2001; Tocher, Mourente, & Sargent, 1992), on the sensory differences between wild and farmed turbot (Prost, Sérot, & Demaimay, 1998), and on the quality changes deriving from high pressure (Chevalier, Le Bail, & Ghoul, 2001), or thermal processing (Madeira & Penfield, 1985). More recently, studies on the sensory, microbial and biochemical changes occurring in farmed turbot during refrigerated storage have been initiated (Aubourg, Piñeiro, Gallardo, & Barros-Velázquez, 2005; Rodríguez, Barros-Velázquez, Ojea, Piñeiro, & Aubourg, 2003).

With the aim of having a better understanding about the potential applications of slurry ice technology, in the present work the effect of this advanced storage system on quality losses and on the shelf life of farmed turbot was evaluated. The results were compared with a parallel study addressing the use of flake ice. To this end, the evolution of the sensory features, microbial activity, and the modifications affecting the most relevant biochemical components, basically lipids, proteins and nucleotides, was evaluated in farmed turbot stored in either slurry ice or flake ice for 40 days.

2. Materials and methods

2.1. Refrigeration systems

Slurry ice was prepared using a FLO-ICE prototype (Kinarca S.A.U., Vigo, Spain). The composition of the flow ice binary mixture was 40% ice and 60% water, prepared from filtered seawater (salinity: 3.3%). The temperature of the slurry ice mixture was −1.5 °C and the temperature of the turbot specimens was in the range of −1 °C/−1.5 °C. Flake ice was prepared using freshwater with an Icematic F100 Compact device (Castelmac SPA, Castelfranco, Italy). The temperature of turbot specimens stored in flake ice was in the range of 0 °C/1 °C. The fish specimens were surrounded by either slurry ice or flake ice at a fish:ice ratio of 1:1, and stored for up to 40 days in a refrigerated room at 2 °C. When required, the ice mixtures were renewed.

2.2. Fish material, processing and sampling

Two-year old farmed turbot (*Psetta maxima*) specimens were obtained from the Stolt Sea Farm, S.A. (Carnota, Galicia, Spain). Fish specimens were sacrificed in a seawater–ice mixture and then kept in ice for 10 h as they arrived at our laboratory. The fish specimens were not headed nor gutted. The length of the fish was 40–45 cm, the width was 29–35 cm, and the weight was 1400–1700 g. Three different batches were used and studied separately along the whole experimental period for each type of ice. Samples were taken from each batch on days 0, 2, 5, 9, 14, 19, 22, 26, 29, 33, 36 and 40. Once whole fish had been subjected to sensory analysis, the white muscle was separated and homogenised for microbiological and biochemical analyses. All sensory, biochemical and microbiological analyses were performed in triplicate.

2.3. Sensory analyses

Sensory analysis was conducted by a sensory panel consisting of five experienced judges, according to traditional guidelines (Table 1) concerning fresh and chilled fish (Council Regulation, 1990). Four categories were ranked: highest quality (E), good quality (A), fair quality (B) and unacceptable quality (C). Sensory assessment of the fish included the following parameters: skin, external odor, gills, consistency and flesh odor. The scores of the different panelists were averaged.

2.4. Microbiological analyses

Samples of 25 g of fish muscle were dissected aseptically from chilled turbot specimens, mixed with 225 ml of peptone water, and homogenised in a stomacher (Seward Medical, London, UK). Serial dilutions from the microbial extracts were prepared in peptone water as previously described (Ben-Gigirey, Vieites Baptista de Sousa, Villa, & Barros-Velázquez, 1998; Ben-Gigirey, Vieites Baptista de Sousa, Villa, & Barros-Velázquez, 1999). Total aerobic counts and anaerobes were investigated in Plate Count Agar (PCA, Oxoid Ltd., London, UK) by standard laboratory methods, as previously described (Ben-Gigirey et al., 1998, 1999). Lactose-fermenting *Enterobacteriaceae* (coliforms) were investigated carried out in Violet Red Bile Agar (VRBA medium, Merck, Darmstadt, Germany) following the

Table 1
Scale employed for evaluating freshness of chilled turbot

Attribute	Highest quality (E)	Good quality (A)	Fair quality (B)	Unacceptable (C)
Skin aspect	Transparent mucus; very intense pigmentation	Milky mucus; insignificant pigmentation losses	Slightly grayish mucus; pigmentation without shine	Widely opaque mucus; important pigmentation losses
External odor	Sharply seaweedy and shellfish	Weakly seaweedy and shellfish	Slightly sour and putrid	Sharply sour and putrid
Gills	Brightly red; without odor; lamina perfectly separated	Rose colored; without odor; lamina adhered in groups	Slightly pale; fishy odor; lamina adhered in groups	Grey-yellowish color; intense ammonia odor; lamina totally adhered
Consistency	Presence or partial disappearance of rigor mortis symptoms	Firm and elastic; pressure signs disappear immediately and completely	Elasticity notably reduced; presence of mechanical signs	Important shape changes due to mechanical factors
Flesh odor	Sharply seaweedy and shellfish	Weakly seaweedy and shellfish	Slightly sour and putrid	Sharply sour and putrid

manufacturer's instructions. The proteolytic phenotype was investigated in casein–agar medium (Phaff, Starmer, Lachance, & Ganter, 1994), as previously described (Ben-Gigirey, Vieites-Baptista de Sousa, Villa, & Barros-Velázquez, 2000).

2.5. Total volatile basic nitrogen assay by steam-distillation

Total volatile base-nitrogen (TVB-N) values were measured by the Antonacopoulos method (Antonacopoulos, 1960), with the modifications described elsewhere (Aubourg, Sotelo, & Gallardo, 1997). Briefly, fish muscle (10 g) was extracted with 6% (w/v) perchloric acid and brought up to 50 ml, the TVB-N content being determined, after steam-distillation of the acid extracts rendered alkaline to pH 13 with 2% (w/v) NaOH, by titration of the distillate with 10 mM hydrochloric acid. The results were expressed as mg TVB-N kg^{-1} muscle.

2.6. Trimethylamine assay

Trimethylamine-nitrogen (TMA-N) values were obtained by the picrate method, as previously described (Tozawa, Erokibara, & Amano, 1971). This involves the preparation of a 5% (w/v) trichloroacetic acid extract of fish muscle (40%). Results were expressed as mg TMA-N kg^{-1} muscle.

2.7. Nucleotide analysis and pH determination

Nucleotide extracts were prepared according to the method of Ryder (1985) and were stored at −30 °C until analysis. Nucleotide analysis was performed by HPLC using a Beckman device provided with the programmable solvent module 126 (Beckman), and the scanning detector module 167 (Beckman) connected to System Gold software, version 8.1 (Beckman). Separations were accomplished on a reverse-phase Spherisorb ODS-2 C_{18} 250 × 4.60 mm column (Waters, Milford, MA), with an internal particle diameter of 5 μm. The composition of the mobile phase was as follows: solvent A was composed of 0.04 M KH_2PO_4 + 0.006 M K_2HPO_4, pH 7; solvent B was acetonitrile. The solvents were filtered through a 0.45 μm aqueous filter before use. Separations were carried out using a continuous gradient elution. The eluent was monitored at 254 nm and the running time was 10 min. Standard curves for adenosine 5′-triphosphate (ATP) and each compound involved in its degradation pathway [adenosine 5′-diphosphate (ADP), adenosine 5′-monophosphate (AMP), inosine 5′-monophosphate (IMP), inosine (Ino) and hypoxanthine, (Hx)] were constructed in the 0–1 mM range. All nucleotide standards were obtained from the Sigma Chemical Co. (St. Louis, MO). The widely used *K* value was calculated according to the following

concentrations ratio: K value = 100 × (Hx + Ino)/(ATP + ADP + AMP + IMP + Ino + Hx).

The pH was determined using a 6-mm diameter insertion electrode (Crison, Barcelona, Spain).

2.8. Lipid damage analyses

The lipid fraction was extracted using the Bligh and Dyer method (Bligh & Dyer, 1959). The free fatty acid (FFA) content was determined by the Lowry and Tinsley method, based on complex formation with cupric acetate–pyridine (Lowry & Tinsley, 1976). The results were expressed as g FFA kg^{-1} lipids. The formation of interaction compounds was investigated by means of fluorescent properties. To do so, fluorescence formation (Perkin–Elmer LS 3B) at 393/463 nm and 327/415 nm was studied as previously described (Aubourg, Medina, & Gallardo, 1998; Aubourg et al., 1997). Relative fluorescence (RF) was calculated as follows: $RF = F/F_{st}$, where F is the fluorescence measured at each excitation/emission maximum, and F_{st} is the fluorescence intensity of a quinine sulfate solution (1 mg l^{-1} in 0.05 M H_2SO_4) at the corresponding wavelength. The fluorescence ratio (FR) was calculated as the ratio between both RF values: $FR = RF_{393/463\,nm}/RF_{327/415\,nm}$. The FR value was analysed in the aqueous phase resulting from the lipid extraction.

2.9. Protein analyses

Sarcoplasmic protein extracts were prepared in a low-ionic-strength buffer composed of 10 mM Tris–HCl, pH 7.2 + 50 mM PMSF (pentamethyl sulphonic acid). A quantity of 500 mg of muscle was homogenised for 60 s in 4 ml of the buffer solution, as previously described (Piñeiro et al., 1999). Then, extracts were centrifuged at 12,500 rpm for 15 min in a JA20.1 rotor (J221-M centrifuge, Beckman-Coulter, London, UK) at 4 °C, and the supernatants were recovered. All extracts were maintained at −80 °C until analysis. Protein concentrations in the extracts were determined by means of the protein microassay method (Bio-Rad Laboratories Inc. Hercules, CA). A standard curve constructed for bovine serum albumin was used as reference.

2.10. Statistical analyses

Data from the different chemical measurements were subjected to one-way analysis of variance; comparison of means was performed using a least-squares difference (LSD) method (Statsoft, 1994). The SPSS software (SPSS Inc., Chicago, IL) was also used to explore the statistical significance of the differences between batches, this including multivariate contrasts and multiple comparisons by the Scheffé and Tukey tests. A confidence interval at the 95% level ($p < 0.05$) was considered in all cases.

3. Results and discussion

3.1. Comparative sensory quality

According to the results of the sensory analyses, the turbot specimens stored in slurry ice maintained good quality, being classified in the E or A categories up to day 22 (Table 2). After this time, quality decreased, and by day 33 the turbot stored in slurry ice was no longer acceptable. The main aspects related to quality loss were the gill odor and color. In contrast with these results, the good sensory quality, E and A categories, of farmed turbot specimens stored in flake ice were maintained only up to day 14, such turbot specimens being rejected on day 22. In the case of turbot stored in flake ice, the presence of abundant skin mucus and the external odor were the limiting factors of acceptability. However, and although farmed turbot stored in flake ice has a longer shelf life than other common medium-sized fish species, such as albacore (Pérez-Villarreal & Pozo, 1990) or hake (Ruíz-Capillas & Moral, 2001), the storage of turbot in slurry ice allowed a significant extension of its shelf life, from 14 to 22 days.

3.2. Comparative microbial development

The total aerobic counts only varied significantly ($p < 0.05$) after 19 days of storage in the slurry ice batch, this indicating a slower growth of this microbial group with respect to the flake ice batch, where aerobic counts

Table 2
Sensory evaluation of farmed turbot during its chilled storage

Attribute	Initial	Days of storage in slurry ice											Days of storage in flake ice										
	0	2	5	9	14	19	22	26	29	33	36	40	2	5	9	14	19	22	26	29	33	36	40
Skin aspect	E	E	E	A	A	A	A	B	B	B	C	C	E	A	A	A	B	C	C	C	C	C	C
External odor	E	E	E	A	A	A	A	B	B	B	C	C	E	A	A	A	B	B	C	C	C	C	C
Gills	E	E	A	A	A	A	A	B	B	C	C	C	A	A	A	A	A	B	B	B	C	C	C
Consistency	E	E	E	E	A	A	A	B	B	B	C	C	E	E	A	A	A	B	B	B	C	C	C
Flesh odor	E	E	E	E	E	A	A	A	A	B	C	C	E	E	A	A	A	A	A	B	B	C	C

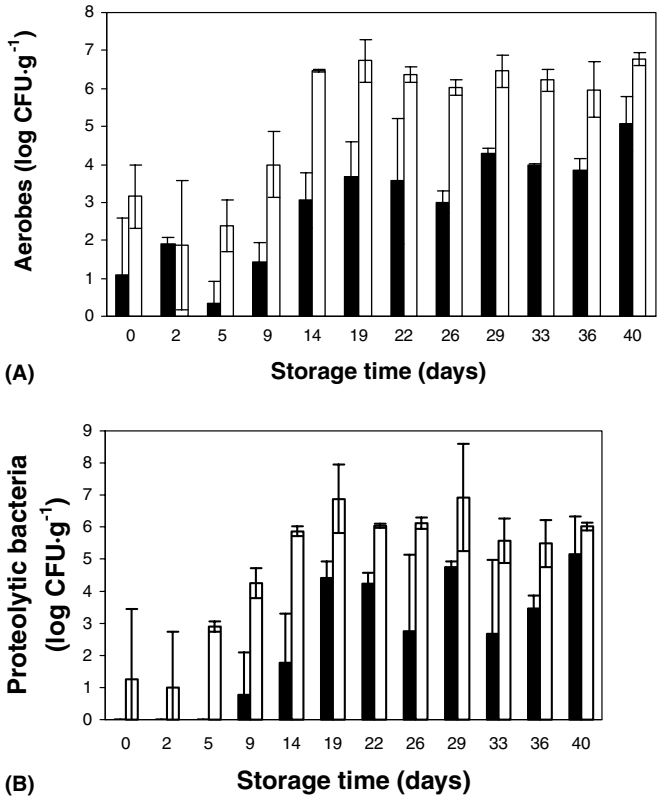

Fig. 1. Comparative evolution of the aerobes (A) and proteolytic bacteria (B) in turbot muscle during storage in slurry ice (black bar) or flake ice (white bar). The differences found for aerobes and proteolytic bacteria between the flake ice and slurry ice batches were statistically significant ($p < 0.05$).

above 10^6 CFU g^{-1} were determined after 14 days of storage (Fig. 1A). A similar type of behavior was observed for proteolytic bacteria (Fig. 1B). Thus, the counts of proteolytic bacteria in turbot muscle stored in slurry ice did not reach levels of 10^5 CFU g^{-1} until very advanced storage periods in slurry ice (40 days), these being significantly ($p < 0.05$) lower than those observed in the flake ice batch after only 14 days of storage (7.5×10^6 CFU g^{-1}). The counts of anaerobes in turbot muscle stored in slurry ice did not vary significantly ($p < 0.05$) with storage, being in all cases below 10^3 CFU g^{-1}. These results clearly indicate the very slow growth of this microbial group in turbot muscle stored in slurry ice. In contrast to the results obtained for slurry ice, the counts of anaerobes in turbot muscle stored in flake ice varied significantly ($p < 0.05$) after 26 days of storage, reaching counts above 3.8×10^4 CFU g^{-1} at that time. With respect to the development of coliforms in turbot muscle stored in slurry ice, these did not vary significantly along the 40 days of storage. Thus, it should be remarked that the average counts of coliforms were below 10 CFU g^{-1}, and only reached a level of 12 CFU g^{-1} after 36 days of storage in slurry ice. In contrast, turbot muscle stored in flake ice exhibited a significant ($p < 0.05$) increase in the coliforms counts after 22 days of storage, reaching numbers close to 10^4 CFU g^{-1} after 29 days of storage.

According to the Tukey and Scheffé tests, the results obtained indicated statistically significant differences ($p < 0.05$) between batches for all four microbial groups. These findings clearly indicate a significantly slower growth of the four microbial groups investigated in turbot muscle subjected to storage in slurry ice as compared with traditional flake ice.

3.3. Comparative biochemical quality

No statistically significant differences were observed in the 0–9 day period for the pH value of turbot muscle stored in slurry ice (Fig. 2A). A slight increase in pH was observed in this batch on day 14. However, the pH value decreased on day 29 but increased after that day up to the end of the experiment (Fig. 2A). By contrast, turbot stored in flake ice exhibited pH values higher than 6.50 and 6.70 after 14 and 19 days of storage, respectively, these figures being considerably above the pH values described in this work for turbot stored in slurry ice (Fig. 2A). As expected from the results obtained, statistical analysis confirmed that the lowest pH values determined for turbot stored in slurry ice were significantly ($p < 0.05$) below those exhibited by turbot muscle stored in flake ice. These results indicate a better control of both endogenous and microbial alkalinising mechanisms in turbot muscle as a consequence of storage in

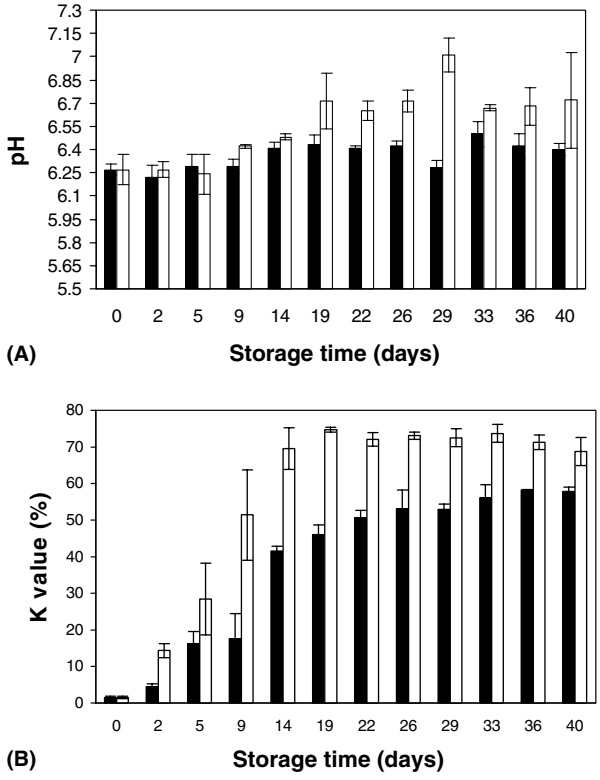

Fig. 2. Comparative evolution of the pH value (A) and the nucleotide degradation rate, as determined by the *K* value (B) in turbot muscle during storage in slurry ice (black bar) or flake ice (white bar). The differences found for pH and *K* value between the flake ice and slurry ice batches were statistically significant ($p < 0.05$).

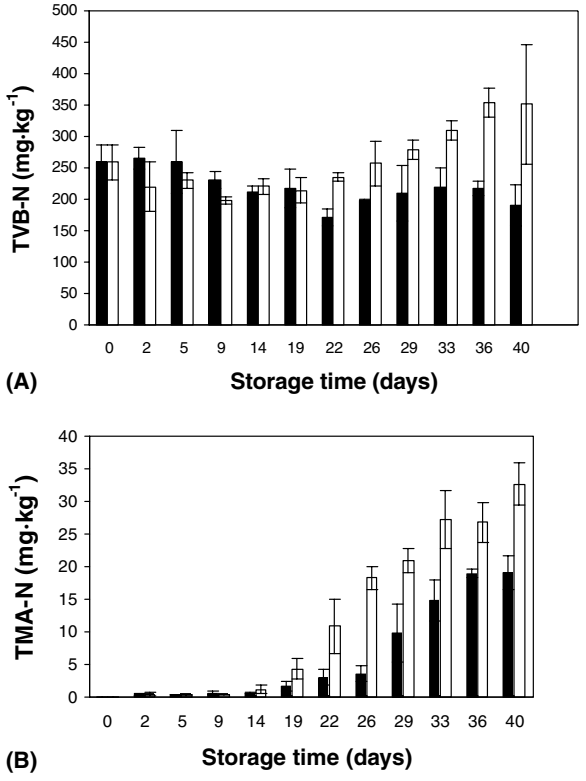

Fig. 3. Comparative formation of total volatile base-nitrogen (TVB-N)(A) and of trimethylamine-nitrogen (TMA-N) (B) in turbot muscle during storage in slurry ice (black bar) or flake ice (white bar). The differences found for TVB-N and TMA-N between the flake ice and slurry ice batches were statistically significant ($p < 0.05$).

slurry ice, as compared to storage in flake ice. Unlike the results obtained in this study, previous reports have also described steady increases in the pH value for other fish species stored in flake ice (Nunes et al., 1992; Ruíz-Capillas & Moral, 2001).

Nucleotide degradation along storage was studied in turbot muscle stored in either slurry ice or flake ice on the basis of the *K* value (Fig. 2B). The *K* value increased in the slurry ice batch to values close to 40 by day 14, this being followed by a slower gradual increase to a *K* value above 50 by day 40. Thus, the *K* values of the turbot specimens stored in slurry ice proved to be considerably lower than those found in turbot stored in flake ice: in the latter case, the *K* values determined reached levels higher than 50 and 70 after 9 days and 14 days of storage, respectively (Fig. 2B). Statistical analysis confirmed that the rate of nucleotide degradation, as determined by the *K* value, was significantly ($p < 0.05$) lower for turbot stored in slurry ice than for turbot stored in flake ice, this indicating a significant slowing down of the autolytic degradation events of turbot muscle in the former batch.

The TVB-N content of turbot stored in slurry ice showed very slight differences along the storage time (Fig. 3A). Thus, the TVB-N content of turbot stored in slurry ice showed a decreasing trend up to day 22, this being followed by an increasing trend up to the end of the storage period. In all cases, the TVB-N content of turbot stored in slurry ice was very low. By contrast, turbot stored in flake ice exhibited TVB-N values above 300 mg kg^{-1} after 33 days of storage (Fig. 3A). Statistical analysis revealed that the storage of turbot in slurry ice involved a significantly ($p < 0.05$) slower formation of TVB-N in comparison with storage in flake ice. Unlike the results obtained in our study for turbot stored in slurry ice, other authors have reported sharp increases in the TVB-N content of medium-sized fish species, haddock and hake, after 9–12 days of storage in flake ice, this coinciding with the end of the microbial lag phase (Baixas-Nogueras, Bover-Cid, Veciana-Nogués, & Vidal-Carou, 2002; Fernández-Salguero & Mackie, 1987; Ruíz-Capillas & Moral, 2001).

The TMA-N index of turbot muscle increased very slowly in the period between 0 and 26 days of storage in slurry ice (Fig. 3B). After this time, a sharp increase was observed between days 26 and 29, this being followed by a slower increase up to the end of storage. Average TMA-N values below 4 and 5 mg kg^{-1} were obtained for turbot stored in slurry ice on days 22 and 26 of storage, respectively. In contrast, average levels above 11 mg kg^{-1} and 18 mg kg^{-1} g were found in turbot muscle stored for 22 and 26 days in flake ice,

respectively (Fig. 3B). As expected from the results obtained in the present study, the formation of TMA-N in turbot stored in slurry ice proved to be significantly ($p < 0.05$) lower than in turbot stored in flake ice. Unlike the results obtained in our study for turbot in slurry ice, other reports concerning small and medium-sized fish species have described sharp increases in TMA-N contents after 9–12 days of storage in flake ice (Baixas-Nogueras et al., 2002; Pérez-Villarreal & Pozo, 1990; Fernández-Salguero & Mackie, 1987; Ruíz-Capillas & Moral, 2001).

Lipid hydrolysis occurred along the storage of turbot in slurry ice. In this sense, slight differences were observed as time progressed, as determined by the FFA content (Fig. 4A). In comparison with the initial value of 6.0 g kg^{-1} lipids at day 0, a notable increase to a FFA content of 25 g kg^{-1} lipids was observed on day 29, although the final FFA concentration was below 16 g kg^{-1} lipids (Fig. 4A). The rate of lipid hydrolysis in the slurry ice batch proved to be quite similar to that observed in turbot stored in flake ice. However, in the later batch final concentrations close to 25 g kg^{-1} lipids were determined after 40 days of storage (Fig. 4A). As expected from the results obtained, statistical analysis confirmed that slurry ice did not allow any significant reduction in the rate of lipid hydrolysis in turbot muscle ($p < 0.05$) as compared with flake ice. However, it should be noted that turbot, either stored in flake ice or in slurry ice, exhibits a very low rate of lipid hydrolysis in comparison with common fish species such as sardine (Aubourg et al., 1997), horse mackerel (Aubourg, 2001), and blue whiting (Aubourg et al., 1998).

Lipid oxidation was investigated through the formation of fluorescent compounds. The FR showed a gradual increase along the storage time of turbot in slurry ice (Fig. 4B). As compared with the initial value, a significant ($p < 0.05$) increase was observed in this parameter on day 5, followed by an increasing trend up to the end of the storage period. In our hands, FR values were never higher than 2, even after 40 days of storage in slurry ice, while FR values higher than 6 were determined at day 19 in turbot stored in flake ice, these results indicating a remarkable inhibition of lipid oxidation mechanisms in the slurry ice batch. Statistical analysis at the $p < 0.05$ level confirmed the inhibitory effect of slurry ice on the formation of fluorescent compounds in turbot muscle, as compared with flake ice.

With respect to the results of protein extractability from turbot muscle in the low ionic-strength buffer used, a significantly high extractability was observed at all sampling times in the slurry ice batch, even after advanced periods of storage (Fig. 5). These results are clearly higher than the extractability values obtained for turbot muscle when storage was carried out in flake ice (Fig. 5). Moreover, a better stabilisation of the protein fraction above 94 kDa was achieved in turbot muscle subjected to storage in slurry ice as compared with flake ice (data not shown). Previous reports by other authors have proposed that the stabilisation of myofibrilar proteins is directly related to better fish quality (Martínez, Friis, & Careche, 2001; Pérez-Villarreal & Pozo, 1990). These observations agree with the results

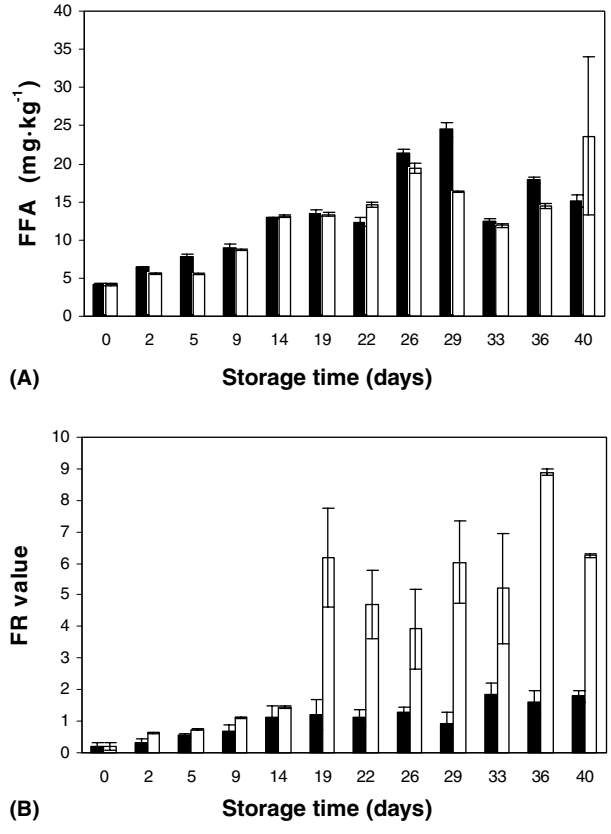

Fig. 4. Comparative release of free fatty acids (FFA) (A) and formation of fluorescent compounds (fluorescence ratio) (B) in turbot muscle during storage in slurry ice (black bar) or flake ice (white bar). The differences found for fluorescent compounds between batches were statistically significant ($p < 0.05$).

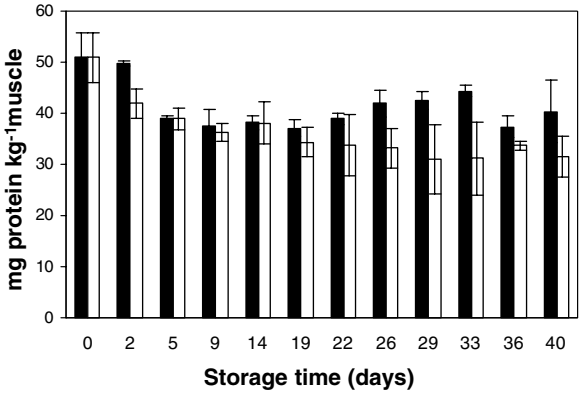

Fig. 5. Comparative evolution of protein extractability in turbot muscle during storage in slurry ice (black bar) or flake ice (white bar). The differences between batches were statistically significant ($p < 0.05$).

obtained in this work. Thus, in comparison with turbot stored in flake ice, the storage of turbot specimens in slurry ice implies a better maintenance of protein extractability and stability even during advanced periods of storage, this coinciding with a better maintenance of texture as determined by sensory analysis.

4. Final remarks

The storage of farmed turbot in slurry ice allowed a remarkably good maintenance of sensory, microbiological and biochemical quality, involving an extension of its shelf life as compared with storage in flake ice. The lower counts of total aerobes, anaerobes, coliforms and proteolytic bacteria, and a good maintenance of pH were achieved. Biochemical analyses pointed to very low TMA-N and TVB-N contents and significantly low rates for both the nucleotide degradation pathway, as determined by the *K* value, and lipid oxidation mechanisms, as determined by the measurement of fluorescent compounds. Furthermore, a greater stability of high molecular wt proteins was observed along storage. On the basis of the results obtained, the use of slurry ice for the storage of farmed turbot is encouraged owing to the better maintenance of quality and the extended shelf life deriving from its use in comparison with flake ice.

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